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Shuttle Imaging Radar-C (SIR-C)

Executive Summary



July 1, 1983

NASA

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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The research described in this publication was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

Abstract

This Executive Summary gives a brief overview of the scientific and technological objectives of the Shuttle Imaging Radar-C (SIR-C) Project. It also provides information regarding the implementation philosophy and approach, and the relationship of the project to the overall SIR program.

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Shuttle Imaging Radar-C (SIR-C)

Project Description

The Shuttle Imaging Radar-C (SIR-C) is the next evolutionary step in a series of spaceborne radar experiments that began with Seasat in 1978 and continued with SIR-A in 1981; SIR-A will be followed by SIR-B, scheduled for 1984. SIR-C will allow a major expansion of our ability to conduct geoscientific investigations using spaceborne radars alone and in conjunction with other experiments. SIR-C will provide increased research observational capability over Seasat and the two previous Shuttle Imaging Radars (SIR-A and -B) because it will allow acquisition of calibrated digital images at two microwave frequencies and with multiple signal polarizations.

Scientific Objectives and the Role of SIR-C in Earth Science

The scientific objectives of the SIR-C mission are (1) to conduct geoscientific investigations that require the observational capabilities of orbiting radar sensors alone or in conjunction with other sensors; this will lead to a better understanding of surface conditions and processes for local areas on the Earth, (2) to explore regions of the Earth's surface that are not well characterized because of vegetation, cloud cover, or alluvial cover; this will provide a better understanding of surface conditions and processes on a global scale, (3) to incorporate this new knowledge into global models of surface and subsurface processes operating on the Earth and other planets.

Technical Objectives

The technical objectives of the SIR-C mission are (1) to develop and demonstrate the capability of obtaining simultaneous L- and C-band radar images at several polariza-

tions, and (2) to develop, in response to scientific requirements, new techniques and remote sensing capabilities that will enhance our ability to use spaceborne radars for Earth observations. The latter of these two objectives includes the generation of circularly polarized data and use of the coherent aspect of radar data. SIR-C will also be the first test of the real-time processing capability of the ADSP (Advanced Digital SAR Processor), conducted in conjunction with a flight mission.

Role in Overall NASA Radar Program

SIR-C is an integral part of the NASA radar program, which is directed toward the use of spaceborne sensors (in this case radars) to further our understanding of the Earth's crustal structure, composition, and surface cover. The radar program consists of SIR-A, SIR-B, and, in addition to SIR-C, future sensors including the Shuttle Scanning Radar Altimeter for land topographic mapping, the Shuttle Polar Ice-Sheet Sounder, and SIR-D.

Status and Estimated Funding

Phase A and Phase B studies have been completed as part of the SAMEX activities. A proposal has been submitted for a FY85 start of implementation with appreciable activity in FY84. This is consistent with a launch in early 1987.

The proposed JPL estimate in FY83 dollars, not including the cost for the science investigations, is:

Fiscal year	84	85	86	87	88	Total
FY83, \$M	1.8	9.15	7.11	2.39	0.36	20.8

I. Science and Research

A. Objectives

The overall objectives of Earth science using remote sensing are to obtain global data sets with consistent viewing geometries and resolution to aid in understanding the planetary-scale processes involving the Earth's crust, oceans, and biomass, and to relate this understanding to such issues as evolution of the Earth's crust, dynamic interactions between the surface and the atmosphere, management of natural resources, prediction of natural disasters, and forecasting climatic fluctuations.

1. The Role of Imaging Radar Sensors

The role of imaging radar sensors in achieving these objectives is to acquire unique data that will aid in answering fundamental questions about continental geology, renewable resources, and ocean dynamics.

Continental Geology: The main goals of remote sensing of continental geology are:

- (1) To determine the global distribution and composition of continental rock units.
- (2) To determine the morphology and structural fabric of the land surface.
- (3) To use this information to understand the present composition and structure of the Earth's crust and its evolution.

The strong sensitivity of the radar return to surface slope variations allows the imaging of very subtle structural features exposed at the surface, or covered by dense vegetation, alluvium or sand (in arid regions), or ice sheets (Antarctic continent). Radar data provide information about surface roughness and large-scale topographic features related to erosional characteristics and resistance of rocks. This information can be used alone or in conjunction with data from other sensors to map lithologic units and model geomorphic processes. Radar data also provide information about the dielectric properties of rocks, properties that are related to porosity or, in some cases, directly to composition. The radar penetration capability is critical for characterizing parts of the Earth's surface that are difficult to explore on the ground and that have not been imaged from space because of vegetation, cloud, or allu-

vial cover. It should be emphasized that up to 45% of the Earth's land surface is covered by heavy vegetation, 10% by sand or alluvium, and 10% by ice sheets (Figure 1). Thus, in total, more than 65% of the Earth's land mass bedrock is not directly accessible to analysis from space using visible or IR sensors. This, along with the fact that many areas of the Earth are often cloud covered, makes a full understanding and use of radar-sensor capability even more critical. In addition, the range-measuring capability of radar systems will allow highly accurate global topographic mapping of the land surface; this is an important element in geophysical modeling of the Earth's interior.

Renewable Resources: The main goals of remote sensing of renewable resources are:

- (1) To determine the global distribution and nature of vegetation and its dynamic behavior, both natural and man-related.
- (2) To determine the extent and nature of the interactions between the biosphere and the atmosphere.

Radar images can be used to determine the extent of vegetation cover and to monitor deforestation, especially in regions that are most often cloud covered, such as the tropics. Because of the radar's sensitivity to the structure of vegetation canopies, radar images can be used in some cases to monitor both the type and vigor of agricultural crops. Imaging radars are also sensitive to soil moisture. Thus, it may be possible to measure global soil-moisture distribution and its dynamic interaction with the atmosphere.

Ocean Dynamics: The main goals of remote sensing of ocean dynamics are:

- (1) To determine sea-surface topography.
- (2) To determine oceanic wind-stress patterns.
- (3) To determine the nature, extent, and dynamics of polar ice cover.

One of the main uses of imaging radar data has been in understanding and monitoring the dynamics of polar ice, especially in predicting the break up of the ice pack. However, preliminary work has also shown that calibrated imaging radar sensors have promise in determining wind-stress patterns, and in monitoring current boundaries and dynamics.

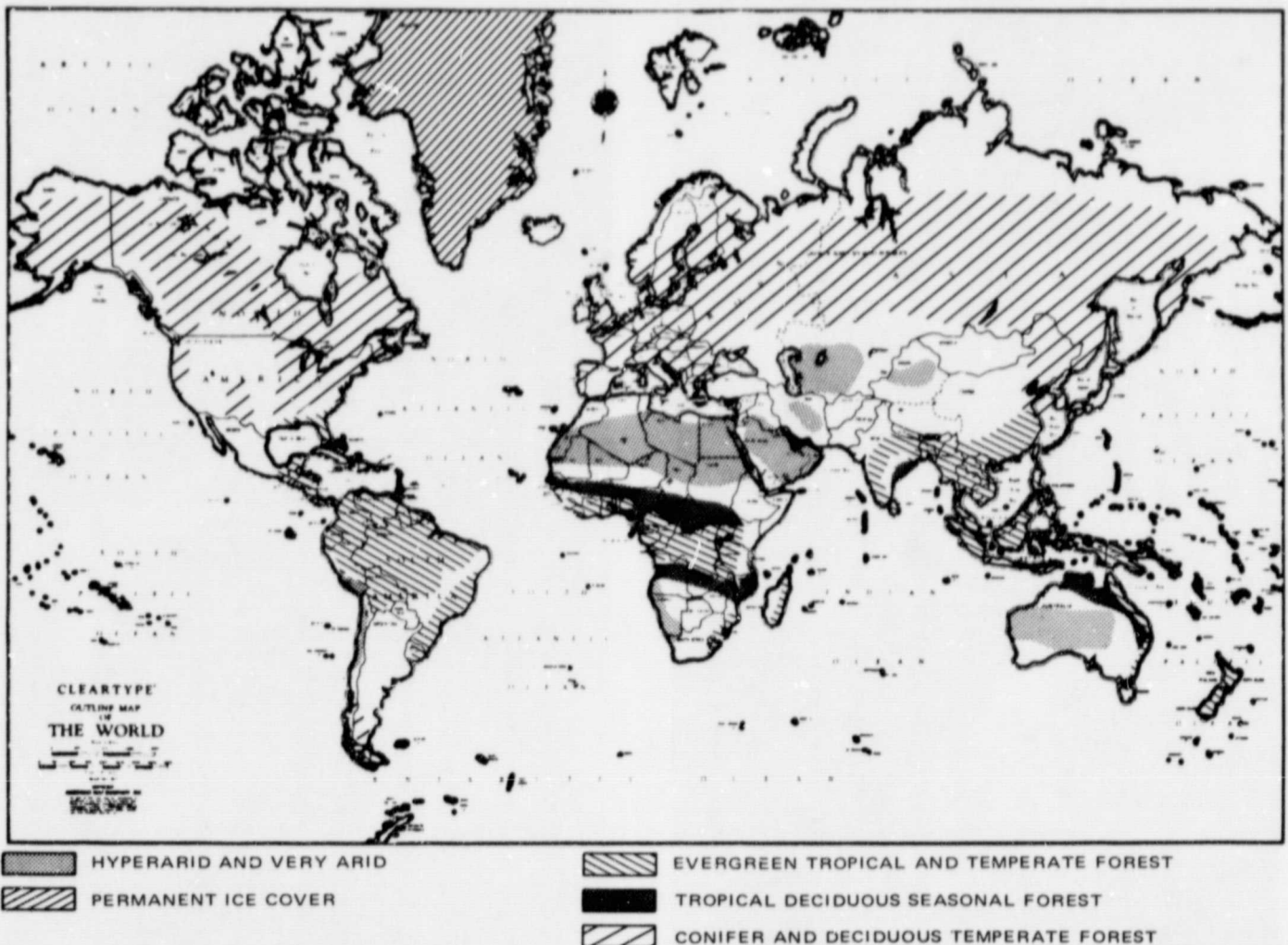


Figure 1. Areas of the Earth covered by vegetation, alluvium, sand, and ice sheets. These are the areas where radar sensors have the highest potential to provide the primary source of geologic information

2. The Role of SIR-C

The role of SIR-C in reaching the overall objectives is to provide unique information about surface units and processes that can be obtained through its multipolarization and multifrequency capabilities. For mapping continental geology, this means an increase in the texture and surface-roughness information derivable from remote-sensing data. In renewable-resource studies, better estimates can be made of vegetative composition and health because leaf orientation, canopy structure, and soil moisture can be determined. For ocean dynamics, a wider range of wave spectra can be imaged, allowing a better estimate of the response of the surface to wind stress and current motion.

B. Examples of Geoscience Investigations

Imaging radars, alone and in conjunction with other sensors, have been shown to have unique capabilities that

are important in addressing Earth-science questions. For example, analysis of SIR-A images of Egypt have demonstrated the potential of mapping subsurface features and bedrock with imaging radars in hyperarid regions (McCauley, et al., 1982, and Figure 2). Moreover, preliminary studies in the Mojave Desert of California indicate that it may be possible to penetrate alluvial cover and map buried surfaces in more environments than was previously thought (Figure 3). It is estimated that about 10% of the Earth's land surface is amenable to such investigations (Figure 1).

The surface roughness and textural information provided by radar images has also been shown to be important for lithologic mapping. An unsupervised classification map was generated with coregistered Seasat, SIR-A, Landsat, and Heat Capacity Mapping Mission (HCMM)



N ↗

0 10 km

Figure 2. images of an area in the western desert of Egypt: (a) SIR-A; (b) Landsat. The stream patterns clearly visible on (a) are a result of radar penetration through the sand sheet and the sand dunes

images of Capitol Reef, Utah. Analysis showed that multi-sensor images incorporating both surface roughness and spectral reflectance information are particularly sensitive to facies changes involving relative amounts of shale and sandstone in the units (Evans, 1983, and Figure 4). Preliminary work using quantitative textural analysis has shown that radar-image texture is an important source of geologic information, especially in heavily vegetated regions such as the tropics (Farr, 1983). Radar data have also been used on a research basis to map areas of deforestation (Figure 5) and to delineate areas with different soil moisture content (Ulaby et al., 1983, and Figure 6).

C. Research in Radar Signature

Role of Frequency Diversity: With multifrequency images it will be possible to quantify such phenomena as penetration of vegetation or alluvial overburden, since penetration is a function of frequency. Multifrequency images will also allow a better determination of surface roughness spectra of geologic and ocean surfaces, because of their sensitivity to a wider range of roughness scales.

Role of Polarization Diversity: The addition of multi-polarized radar data will enable us to develop more com-

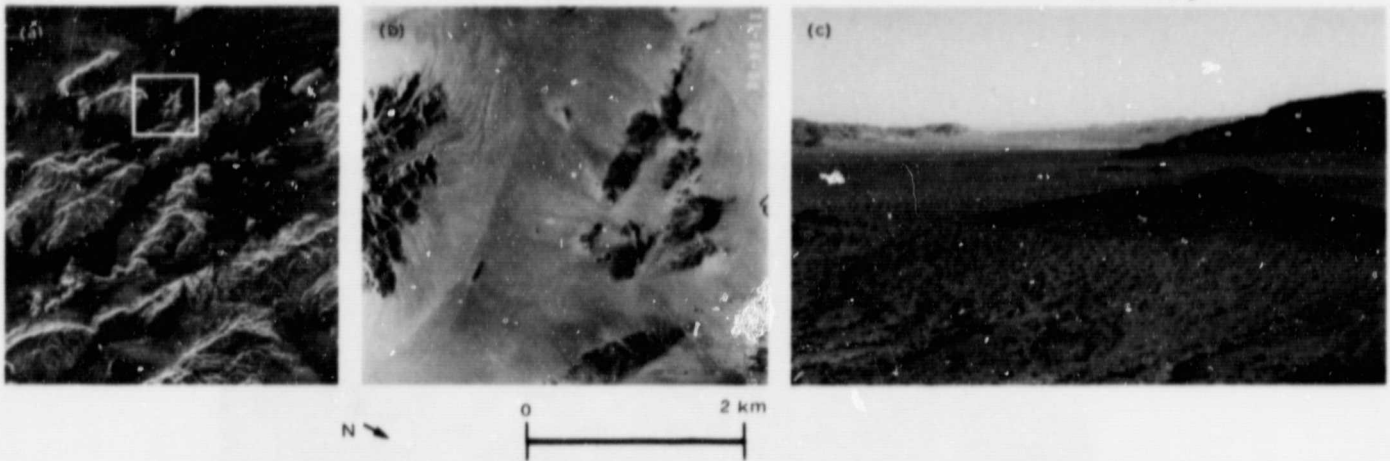


Figure 3. Images of an area in the Mojave Desert, California: (a) Seasat SAR; (b) air photo of area outlined in the SAR image; (c) ground photo of the area. The bright linear features in the Seasat image, which are not visible in the airphoto, seem to be related to partially-buried igneous dikes, as shown in (c)

plete radar signatures for various rock types in different climates; these signatures will aid in rock-type characterization. Multipolarized radar data can be used to separate surface roughness effects from dielectric-constant effects, which is important for both geologic and soil-science studies. Multipolarized radar data are also sensitive to vegetative structure, an important factor in assessing plant stress. Moreover, by combining linearly polarized radar returns, it may be possible to separate scattering by vegetative cover from scattering by the surface under the canopy; the canopies and surfaces, therefore, can be analyzed independently.

II. Technology and Techniques

The SIR-C Project, in addition to the scientific research objectives discussed above, has a number of technical objectives. These are:

- (1) To develop the high-risk, high-payoff technologies required for spaceborne radar systems of the 1990s. These include the development of (a) modular multispectral (L-, C-, and later X-band) sensor hardware, (b) high-power, wide-bandwidth transmitters, (c) large, multifrequency, multipolarization antennas, (d) multiple-beamwidth antennas, (e) real-time digital processors, and (f) postprocessing techniques for data analysis. Some of these technologies are being developed under research tasks; however, SIR-C will use them in the space environment and under real operating conditions.

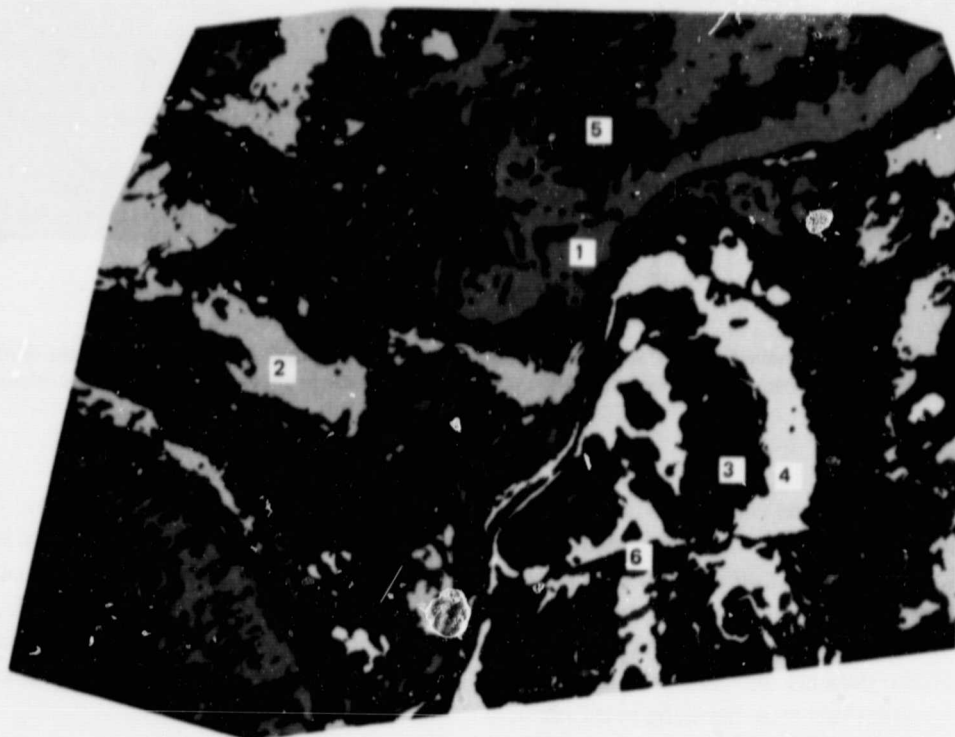
- (2) To develop and demonstrate, from space, techniques that would provide more flexibility in the use of the radar sensors for Earth observations. These techniques include squint mode, multilook mode, burst mode, generation of circularly polarized data, and use of the coherent aspect of radar data.

III. Implementation Philosophy and Approach

A. Overall Design Philosophy—Modular Approach

SIR-C will be designed to capitalize on the hardware and experience gained from SIR-A and SIR-B to the maximum extent possible. Major electronic assemblies will be reflowed with minimum refurbishment. A modular approach will be used to allow easy reconfiguration of, and modification to, the basic sensor. The number of frequency-independent modules will be maximized so that modifications and additions will involve a minimum number of modules. In addition, the use of identical modules for the different channels will increase the flexibility and reliability of the total system. Figure 7 shows a sketch of the SIR-C block diagram with new and existing system elements noted. Figure 7 illustrates the extensive use of the SIR-A and SIR-B development.

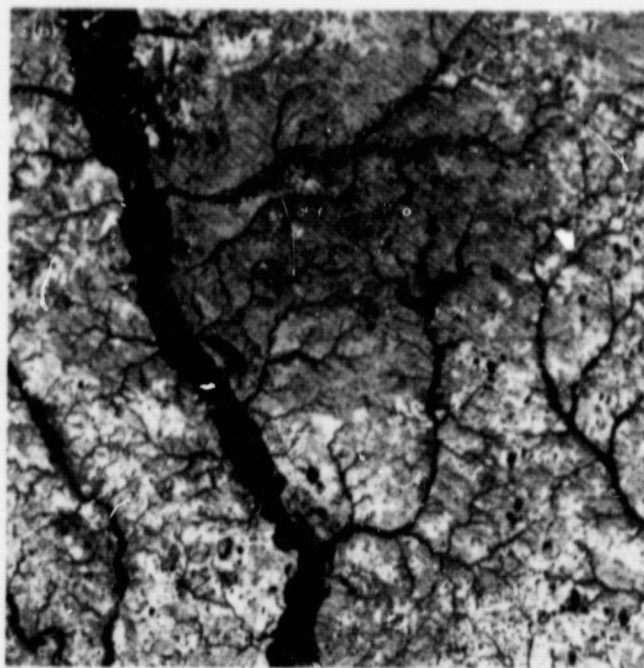
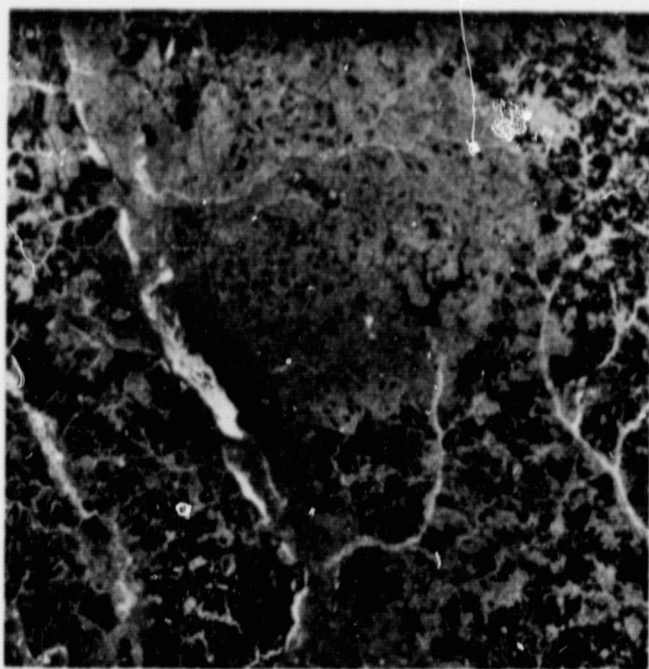
To illustrate, a change in operating frequency from L-band to C-band is accomplished by switching in the appropriate antenna and reprogramming the up converter and down converter. Simultaneous operation at both L- and C-bands can be accomplished by using both antennas and two receivers.



EXPLANATION:

- | | | |
|-----|--|---|
| [1] | | MASSIVE SANDSTONE |
| [2] | | SANDSTONE AND SILTY SANDSTONE |
| [3] | | SANDSTONE CONTAINING 10-35% SHALE |
| | | SANDSTONE CONTAINING 40-60% SHALE |
| | | SHALE CONTAINING 10-35% SANDSTONE |
| | | GYPSUM-BEARING ROCKS |
| [4] | | SHALE WITH <10% SANDSTONE |
| [5] | | SANDSTONE, SILTSTONE, LIMESTONE AND SHALE |
| [6] | | SAND AND GRAVEL, SPARSE VEGETATION COVER |

Figure 4. Unsupervised classification: map of Capitol Reef, Utah, based on Seasat, Landsat, SIR-A, and HCMM images. Units in this classification correlate with a surface-cover map



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Figure 5. Images of an area in the Savannah River floodplain, South Carolina and Georgia: (a) SIR-A; (b) Landsat. Clear cuts from logging operations appear in the radar image as small, dark-gray rectangles

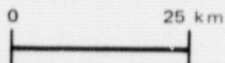
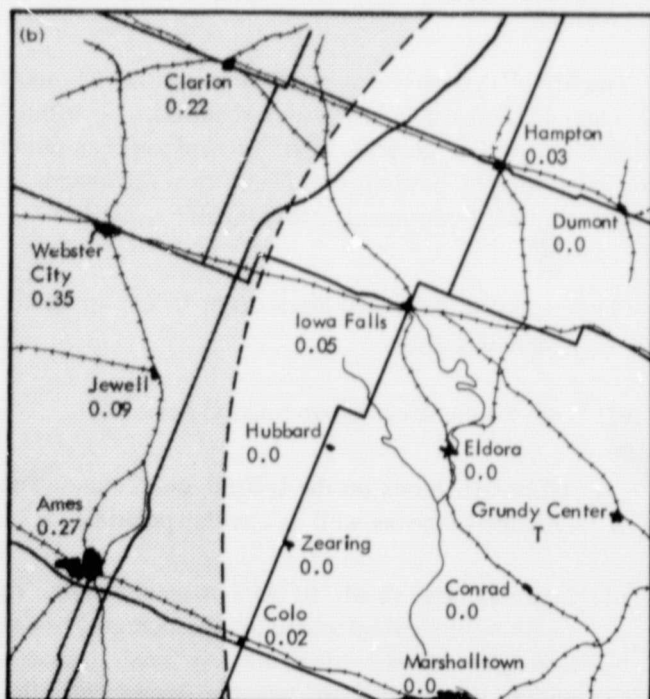


Figure 6. Soil moisture in Ames, Iowa: (a) Seasat image; (b) map of the area with rainfall observations in inches. The high soil moisture associated with the rain produced lighter tones on the radar image

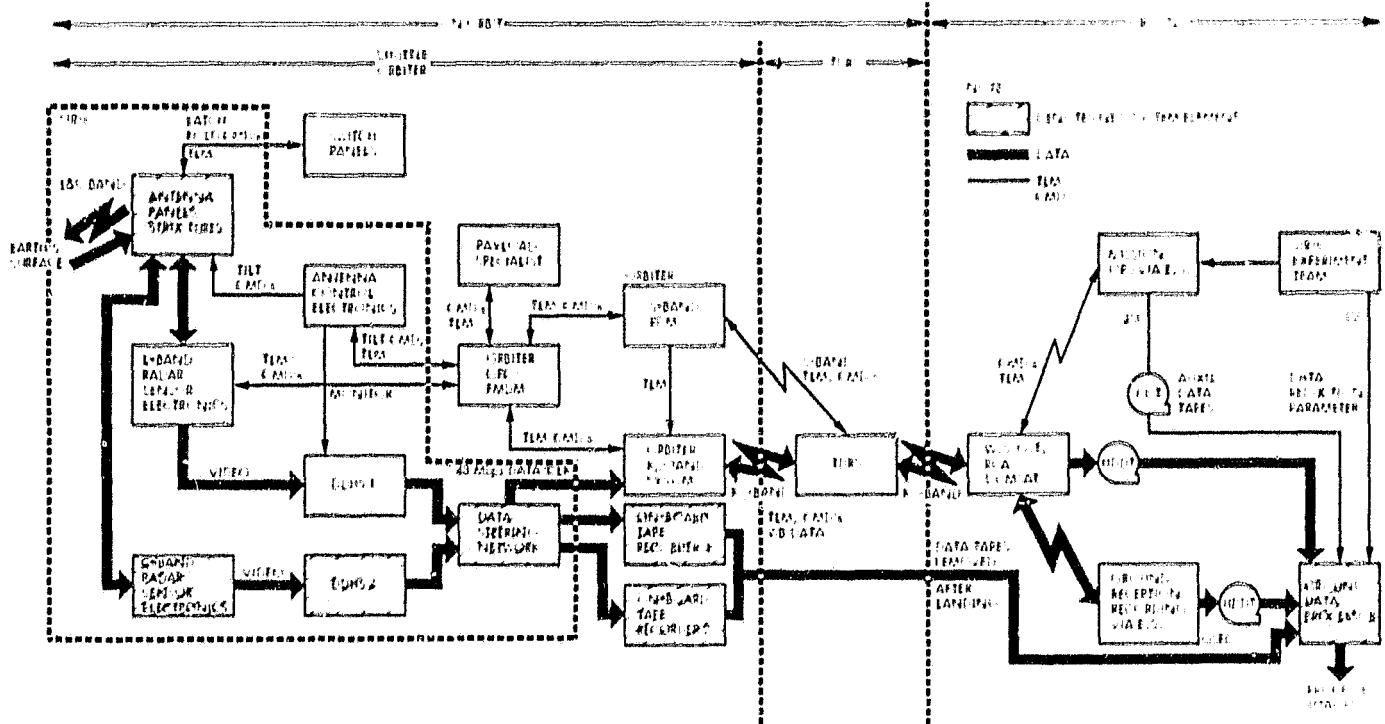


Figure 7. SIR-C system block diagram showing new system elements and those developed for SIR-A and SIR-B

B. Overall Configuration Approach—Software Control

The SIR-C system can be operated in a variety of modes to adapt to different investigative requirements. It has a wide range of configuration flexibility and can be modified and controlled by ground commands, crew commands, or preprogrammed commands. This flexibility includes:

- (1) Selectable incidence angle from 15 deg to 60 deg with 1-deg steps.
- (2) Two frequencies: L-band and C-band.
- (3) All polarizations on the L-band and C-band. This includes linear as well as circular polarization.
- (4) Constant large swath. At large incidence angles, the swath width can be traded off for increased resolution and number of looks. At small incidence angles, the split-beam antenna design will allow increased swath width.
- (5) Burst mode, which allows trade-offs between the number of looks and the swath width for a constant 50-Mb/s data-rate limitation.

C. Sensor Characteristics and Expected Performance

The SIR-C sensor characteristics are described in Table 1. Some of the corresponding performance characteristics are illustrated in Figures 8 and 9.

IV. Project Description and Relationship to Overall SIR Project

SIR-C is one element of the Shuttle Imaging Radar (SIR) program (Figure 10), which consists of the SIR-A, -B, -C, and -D series, the Shuttle Scanning Radar Altimeter (SRA), and the Shuttle Polar Ice Sheet Sounder (SPICES). All these experiments use modular sensors that are complementary and expand on previous development. In this fashion, the cost of conducting these experiments will be appreciably reduced (by as much as 50%) by the repeated use of hardware modules. SIR-C is proposed for a Shuttle polar flight in March 1987. NASA is discussing with the German Space Agency (DFVLR) the possibility of having on the same flight the German Microwave Remote Sensing Experiment (MRSE) sensor. The MRSE sensor will provide simultaneous X-band imagery of the same areas imaged by SIR-C, thus allowing expanded multispectral capability and appreciable scientific payoff, particularly in the area of subsurface penetration studies and radar signature research.

Table 1. SIR-C system characteristics

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Parameter	Value	
	L-Band	C-Band
Frequency, GHz	1.275	5.28
Wavelength, cm	23.5	5.7
Transmitted peak power, kW	1	2
Bandwidth, MHz	12	
Incidence angle, deg	15-60	
Resolution, m	15-30	
Swath width, km	35-120	
Number of looks	4	
Polarization	HH, VV, VH, HV, RCP, LCP	
Antenna length, m	12.1	12.1
Antenna width, m	1.7	0.4
Operation altitude, km	200-300	
Data collection	Digital via TDRSS (50-Mbit link) and two onboard recorders	
Bit rate, Mb/s	46 per channel	
Calibration goal, dB	1 relative, 3 absolute	
Data collection per flight, h	50 (25 on each channel)	
Data processing	Digital	
Modes and configuration control	Can be done by command or programming	

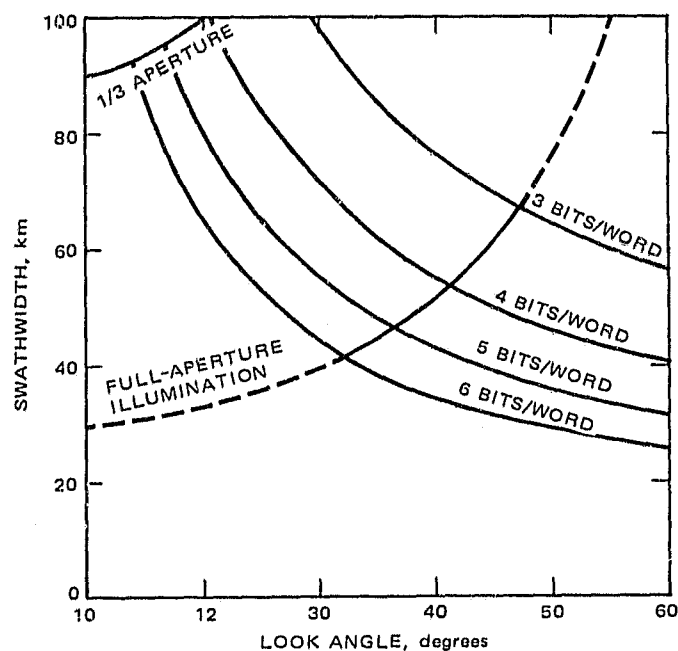


Figure 8. SIR-C swath coverage. Split-beam antenna (1/3 aperture) allows increased swath width at small look angles

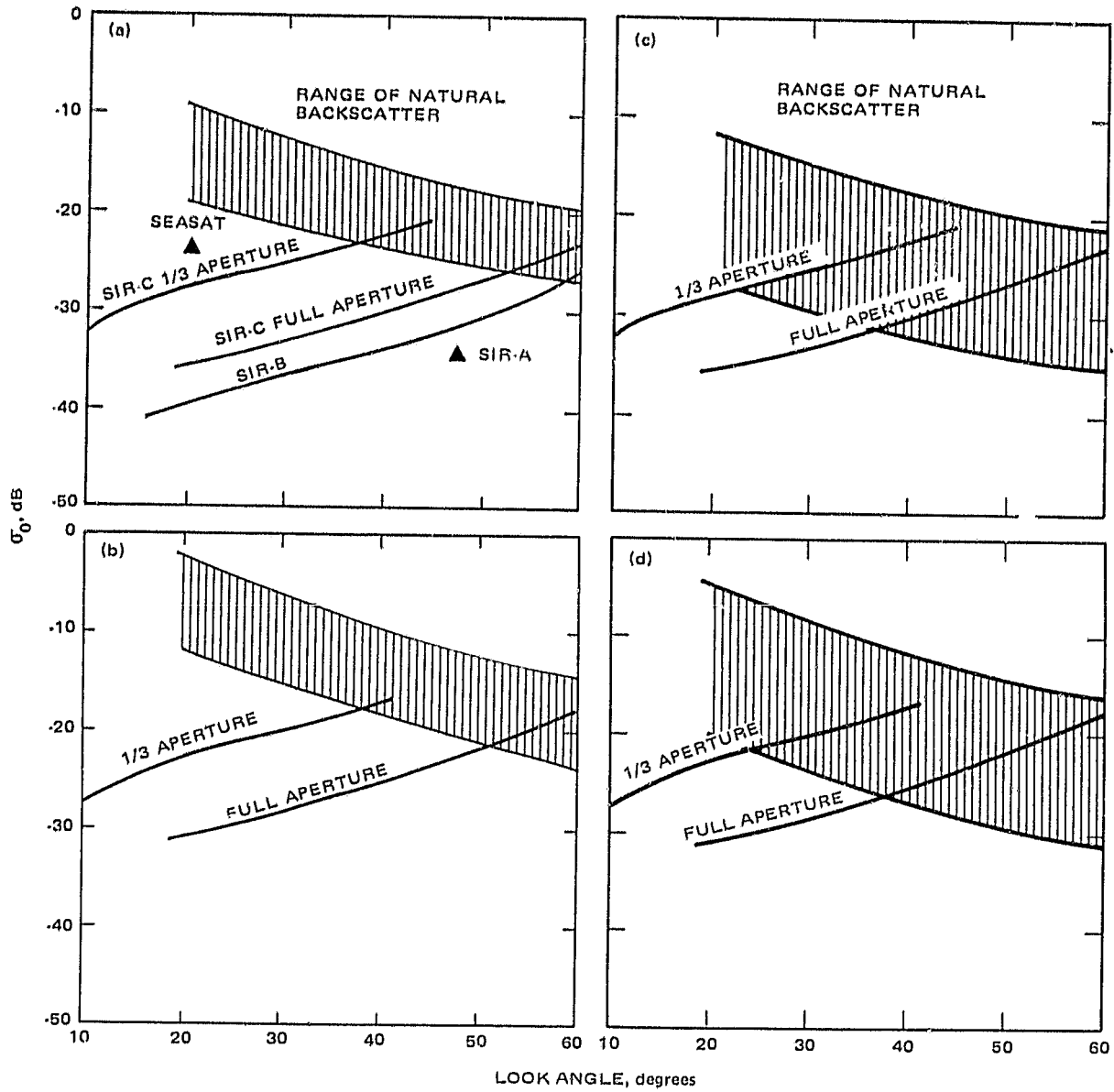


Figure 9. SIR-C system sensitivity (noise equivalent σ_0): (a) L-Band direct polarization with the sensitivities of Seasat, SIR-A, and SIR-B for comparison; (b) C-band direct polarization; (c) L-band cross polarization; (d) C-band cross polarization

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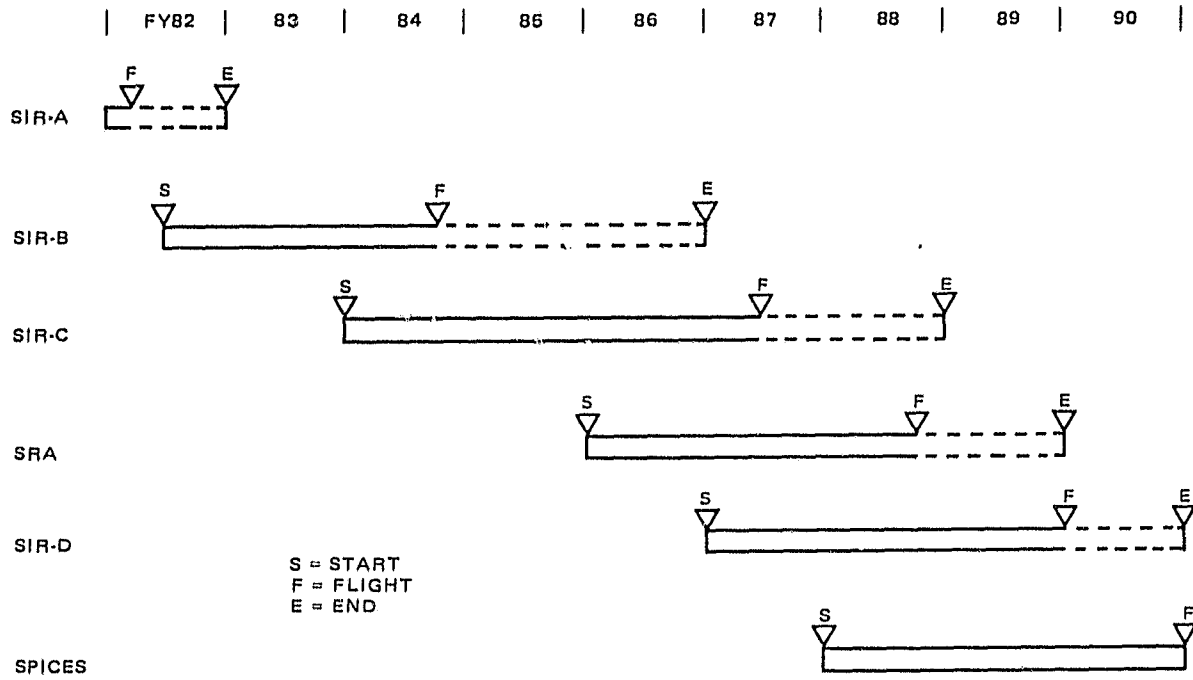


Figure 10. SIR Project elements

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